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Ramjet Tactical Missile Propulsion Status

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ABSTRACT

Internationally, and within the US, there is a considerable interest and corresponding financial investment in hypersonic (Mach 6+) airbreathing missile propulsion to provide the increased speed and standoff ranges desired for future weapon systems. While this experimental work is continuing, there have been significant activities in ramjet (Mach 2-5) missile developments in the US and around the world, involving flight testing and newly deployed missile systems. Anti-ship missiles continue to proliferate and the US has responded with a ramjet missile target development and related weapon studies. Anti-radiation missiles, time-critical strike missiles, and air-air missiles are also in development. Several historical and current programs at ARC are helping to close the gap in US capabilities relative to other nations. This paper will briefly cover international developments in ramjet-powered missiles taking place in recent years, and describe current ramjet missile and propulsion technology developments within the US.

INTRODUCTION

In the late 1900's US ramjet activities were on the decline while many of the world's major powers were holding steady or increasing their efforts. Several recent developments have led to an increased dependence on ramjet propulsion overseas, and more specifically the solid ducted rocket. Domestically, the cyclic nature of ramjet development continued, with all industrial contract activities disappearing in 1999. During this period ARC elected to maintain a capability in tactical ramjet propulsion through capital investments, hiring, and Internal Research and Development. This decision appears to have been warranted, as several requirements have surfaced recently which demand the capabilities only a ramjet engine can offer, and the US armed services have recently shown a renewed interest in ramjet missile propulsion.

This paper will briefly highlight notable overseas ramjet missile activities, and provide a summary of recent US activities and ongoing ramjet programs.

FOREIGN RAMJET MISSILE DEVELOPMENTS

RVV-AE-PD (AA-X-12) -Russia

This medium range beyond-visual-range missile (Figure 1) is being developed by Russia as an improved version of the AA-12 Adder. Five "firings" are reported in 1995 [2] ,and ten ground tests are reported in 1999 [3], with flight tests due to begin shortly thereafter. No definite reports of flight-testing are available, despite earlier claims and the widely published photo of a ground-launch configuration shown in Figure 2. Recent reports indicate technical problems with inlet configuration and fuel efficiency [4]. A solid fuel ducted rocket engine is used with automatic ram pressure controlled throttling. This missile is the primary threat driving the UK BVRAAM missile requirement. The projected timeframe for introduction continues to slip to the right, with international cooperation being a key driver.

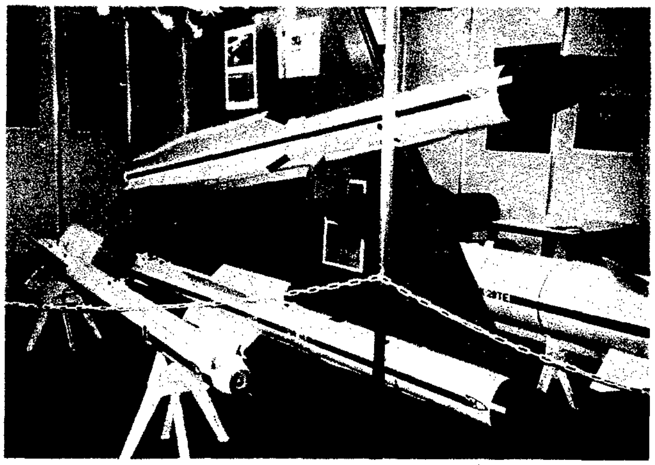

Figure 1 – RVV-AE-PD Missile

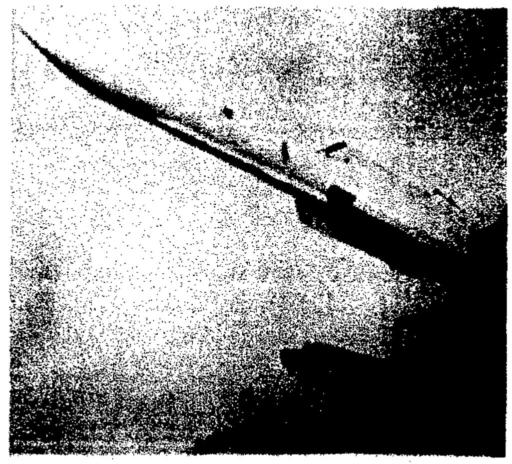

Figure 2 – Ground Launched RVV-AE-PD Missile

[2] International Defense Review, 02-01-96, p. 53
[3] Jane's Missiles and Rockets, Vol. 3, No. 10, October 1999
[4] Aviation Week & Space Technology / October 8, 2001

SS-N-26 (Yakhont) -Russia

The Russian Yakhont anti-ship cruise missile shown in Figure 3 is the basis of the PJ-10 missile being developed by the Russian and Indian BrahMos joint venture. The joint effort was started in 1998, and the first flight occurred on 12 June 2001 (Figure 4). The PJ-10 is expected to be in production in 2003, with an air-launched version following closely behind. An air-launched version of the Yakhont was displayed at the Moscow air show in 1999.

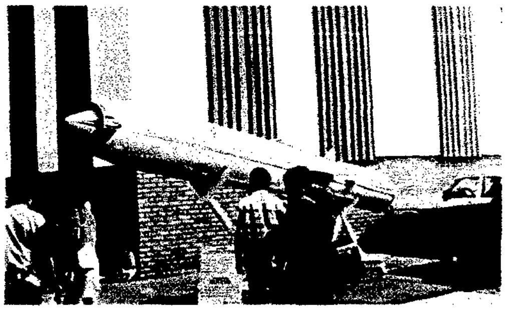

Figure 3 – SS-N-26 (Yakhont) Missile

Figure 4 – BrahMos Missile Launch

SS-N-19 (Shipwreck) -Russia

The configuration of the Russian Shipwreck missile shown in Figure 5 was recently made public [5], and revealed to be a ramjet-powered missile. Although introduced to service in the 1980's little had been made public until recently. The submarine Kursk, lost in the Barents Sea in August 2000, had conducted a SS-N-19 live-firing trial just before it went down.

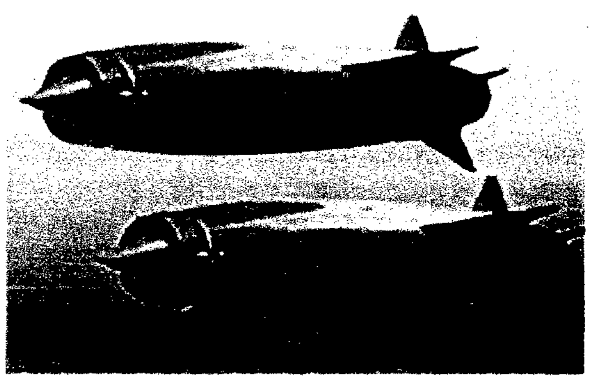

Figure 5 – SS-N-19

[5] Jane's Defense Weekly, 10 September 2001.

SS-N-22 (Sunburn) -Russia

The SS-N-22 missile, or 3M80 Moskit, shown in Figure 6 remains a considerable threat to surface Navies. It is reported to be on China's newly acquired Sovremenny-class guided missile destroyers. The first Chinese test was reported to be September 15, 2001 (6), and up to several hundred are potentially stored in inventory. This has prompted Taiwan to respond with development and flight-testing of the Hsiung Feng III missile. The Hsiung Feng III is a liquid ramjet anti-ship cruise missile developed by the Chung Shan Institute of Science and Technology (CSIST).

(6) THE WASHINGTON TIMES, September 25, 2001

Figure 6 – SS-N-22 Sunburn Missile

SA-6 (Gainful) -Russia

The SA-6 missile shown in Figure 7 is no longer in production, however they have been sold to over 25 different countries and upgrade activities continue. They recently played a prominent role in the 1999 air campaign in Yugoslavia.

Figure 7 – SA-6 Gainful Missile

India has conducted flight tests of their new AKASH missile (Figure 8), which is based in large part on the SA-6. Flight tests were reported from July 2000 to September 2001.

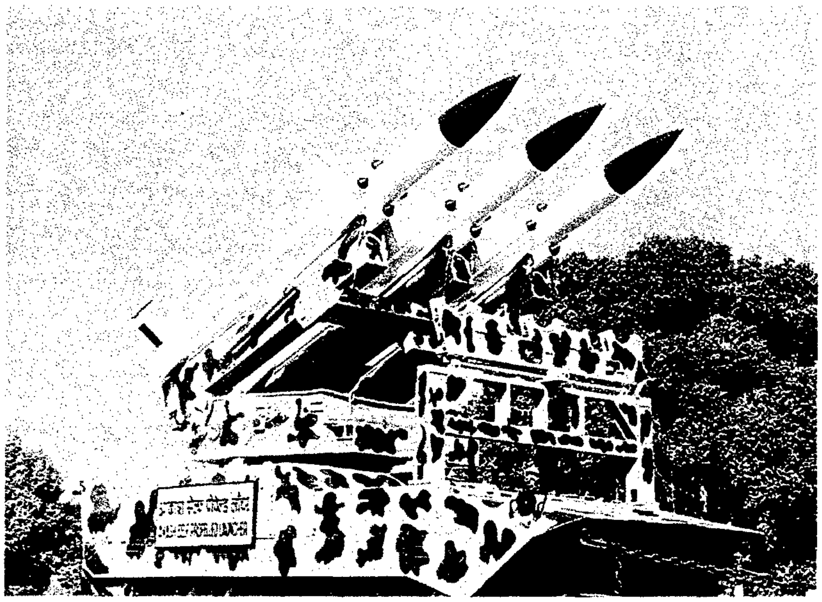

Figure 8 – AKASH Missile (India)

Kh-31 (Krypton) -Russia

The Kh-31 (Figure 9) has made news recently primarily due to its use as a missile target for the US Navy. The Boeing Company has been importing airframes from Russia and modifying them for use as MA-31 aerial targets (Figure 10). The first flight of an MA-31 occurred in August 1996, and 12 more missiles were converted before a contract award to Boeing for an additional 34 targets in 1999. However, Russian export restrictions imposed in 2001 make further deliveries uncertain.

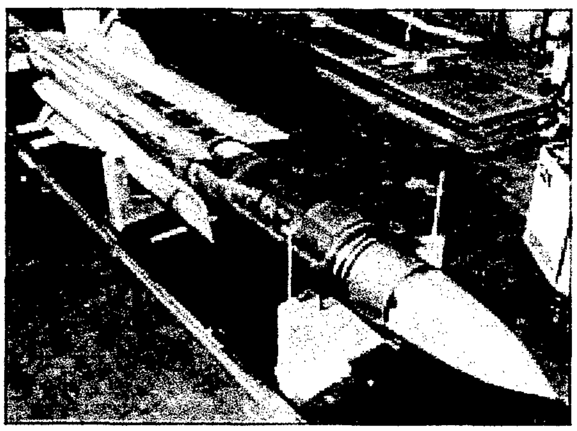

Figure 9 – Kh-31 Krypton Missile

Figure 10 – MA-31 Aerial Target

China and Russia are reportedly [7] jointly developing the KR-1anti-radiation missile, based on the Kh-31P. China and Russia are cooperating on the development, with initial missile deliveries having occurred in 1997 but production is yet to begin.

[7] Flight International Magazine, 10-16 December 1997.

ASMP - France

Aerospatiale Missiles was awarded the $109M VESTA contract in 1996. This program is intended to improve aspects of the existing ASMP (Air-Sol Moyenne Portee) liquid fuel ramjet as well as other missile technologies. Technology developed on the VESTA contract (Figure 11) is applicable to the ASMP-A nuclear missile, as well as the planned anti-ship ANF (Anti-Navire Future) missile shown in Figure 12. Completion of engine ground testing was recently announced.

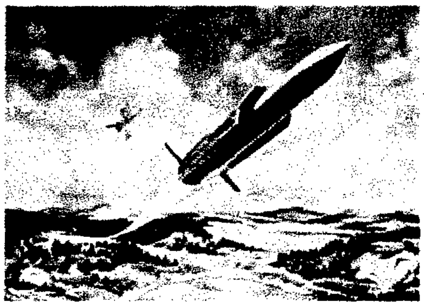

Figure 11 – VESTA Technology Demonstrator

French and German cooperation was started in 1995 on the ANNG (Anti-Navire Nouvelle Generation) program, which was to be an anti-ship missile based on VESTA technology. Germany withdrew from the program in 1997 due to funding constraints, and France continued the work under the name of ANF. The ANF program was put on hold in France in 2000, but the VESTA work continues.

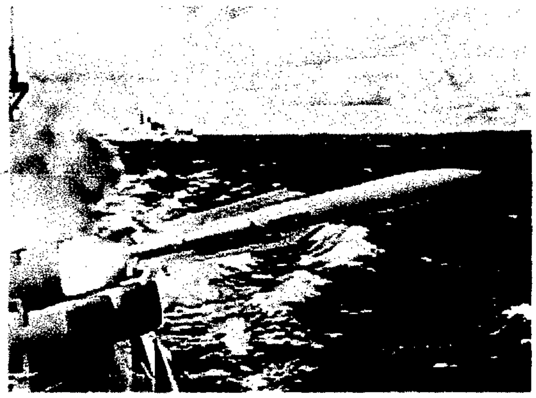

Figure 12 – ANF Missile

China has displayed a model at several airshows of a ramjet-powered air-launched missile similar in configuration to the ASMP missile. The designation Ying-Ji 12 suggests an anti-ship role similar to the planned French ANF missile.

MPSR-1 & 2 - France

A technology demonstration project was conducted in France on the MPSR (Missile Probatoire Stato Rustique). The program included flight test demonstration of the "unchoked" solid ducted rocket (Figure 14). Five flight tests were conducted on the MPSR-1 program, and two under the MPSR-2 program. The ground-launched missiles successfully demonstrated the technology for future applications.

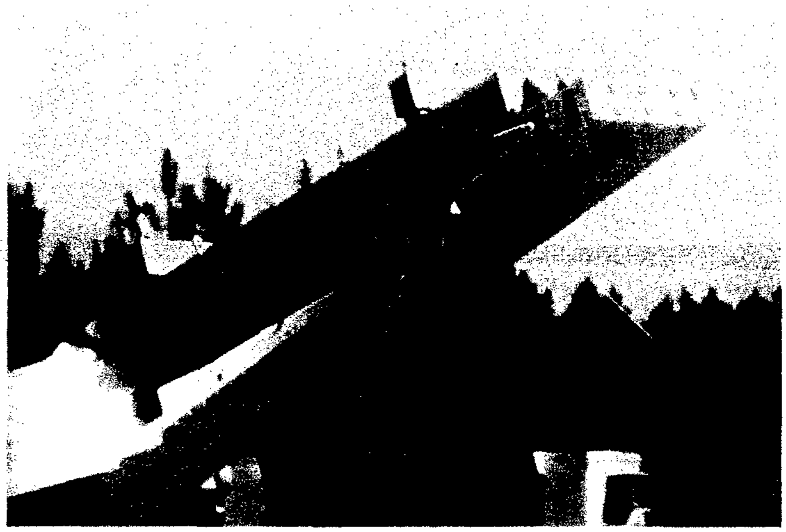

Figure 14 – MPSR Missile

METEOR (UK, France, Germany, Sweden, Spain and Italy)

The competition for the BVRAAM (Beyond Visual Range Air-Air Missile) was led by the UK, with the other European countries contributing to the costs of development. The missile is intended to arm the Eurofighter, and become the European air-to-air missile of the future. Matra BAE (now MBD) was awarded the $1.2B development program in May of 2000 for the Meteor missile (Figure 15).

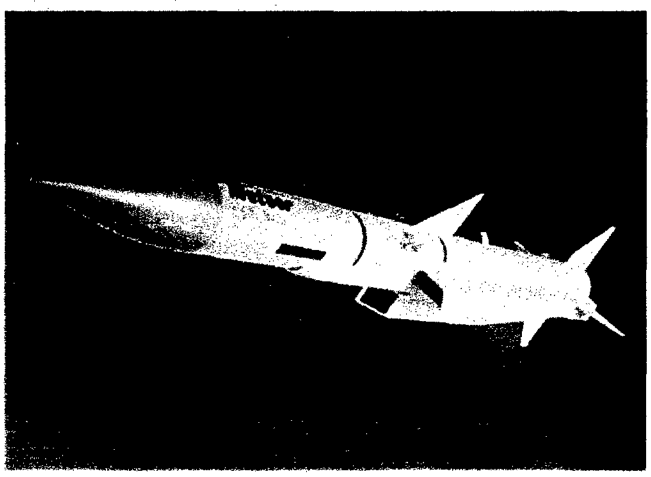

Figure 15 – Meteor Missile

As of this writing all countries have signed to share the development costs except Germany. The contract between the UK and MBAE is still being negotiated, however work has been initiated under corporate sponsorship. Bayern-Chemie of Germany is responsible for the engine development and production.

ARMIGER - Germany

In the early 1990's Germany and France cooperated on the development of a future anti-radiation missile called Aramis. In 1996 France withdrew from the program and it was renamed Armiger in Germany. Germany is currently conducting development airframe testing with captive seeker flights and flight-testing of a rocket boosted airframe with mock inlets.

Figure 16 – Armiger Anti-Radiation Missile

US RAMJET MISSILE DEVELOPMENTS

FASTHAWK (LOW COST MISSILE)

In March 1997, The Boeing Company received an $8 million contract from the U.S. Navy for the Low Cost Missile System (LCMS) Advanced Technology Demonstration (ATD) program, called Fasthawk (Figure 17). The ATD program was to be conducted jointly with the Naval Air Warfare Center, China Lake, Calif. The program progressed to engine testing at China Lake before ending.

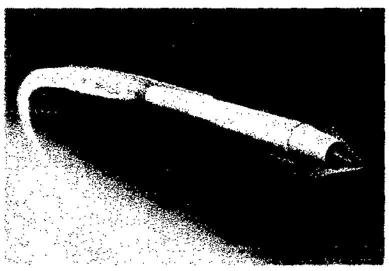

Figure 17 – FASTHAWK (Low Cost Missile)

U.S./JAPANESE DUCTED ROCKET

A cooperative program between the US Army Aviation and Missile Command and Japan was conducted from 1992 to 1997 to develop and demonstrate the technologies required for a solid fuel variable flow ducted rocket. The missile concept investigated advanced fuel formulations, valve design, and combustor geometry. Testing was completed up through ground testing at NAWC China Lake.

VFDR (VARIABLE FLOW DUCTED ROCKET)

The VFDR Advanced Development program was sponsored by the USAF to develop next generation ramjet propulsion capability for tactical missiles. A 7-inch diameter ducted rocket ramjet engine was designed with the objective of retrofit capability with an existing missile forebody (AMRAAM), with only software changes to the missile guidance section (Figures 18 and 19). Component qualification and engine ground testing was conducted from 1987 to 1997, which demonstrated the capability of the engine to meet system environmental requirements, as well as mission durability and performance.

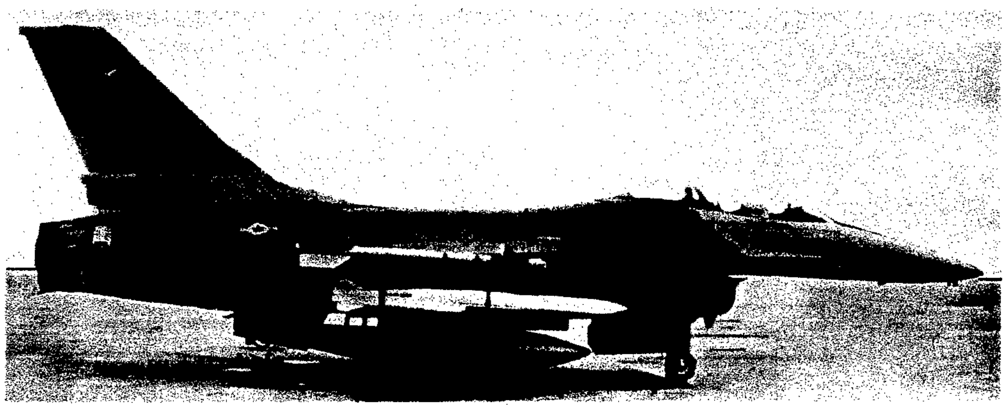

Figure 18 – VFDR/AMRAAM Missile

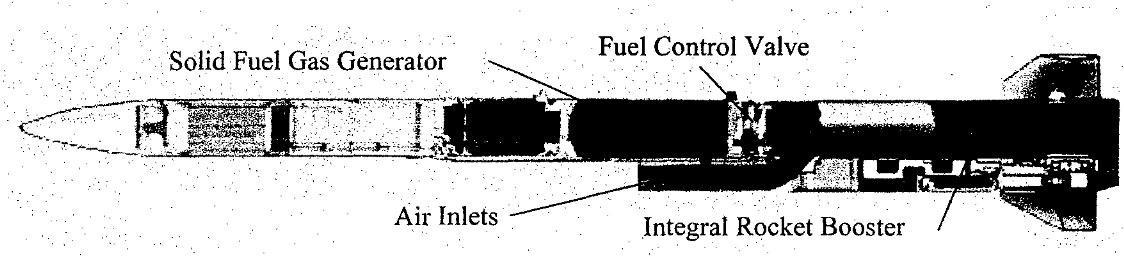

Figure 19 – VFDR Inboard Profile

In 1997, the VFDR program was successfully concluded by a test program at ARC that sequentially built up to two full-system boost-to-sustain transition tests in flight-ready hardware (Figure 20). All motor events associated with transitioning from rocket boost to ramjet sustain operation were executed by an on-board AFD controller, and demonstrated in a series of preliminary tests and two full-system transition

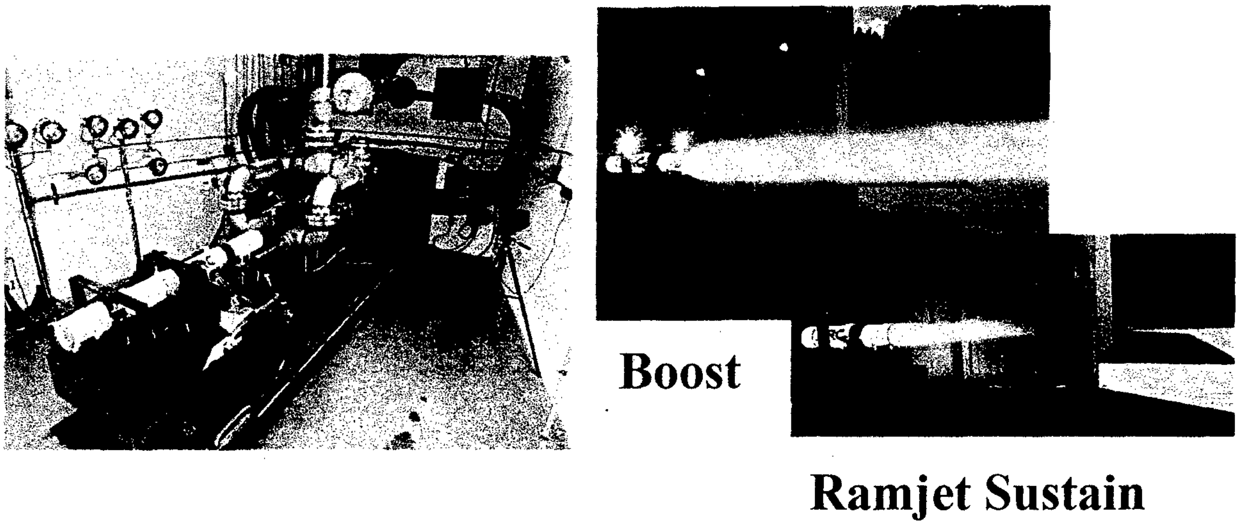

Figure 20 – VFDR Transition Tests

tests. These tests also demonstrated a patented air-bypass test technique as an appropriate method of final ramjet demonstration testing without the added complexities and costs associated with freejet engine testing.

US/FRENCH DR

From 1991 to 1997 a joint US/France Cooperative program was conducted to marry French "Rustique", or unchoked ducted rocket technology (Figure 21) with U.S. advanced fuels and throttled ducted rocket experience. The program was conducted under a Memorandum Of Agreement (MOA) between the USAF and the French Ministry Of Defense. The U.S. part of the program was managed by the Aero-Propulsion and Power Directorate of the Wright-Patterson AFB, with Atlantic Research as the U.S. prime contractor. ONERA was the French prime contractor, with support from CELERG, Aerospatiale, and MATRA. Full scale direct-connect ramjet testing at ARC and ONERA demonstrated the unchoked gas generator configuration using advanced fuels developed by ARC.

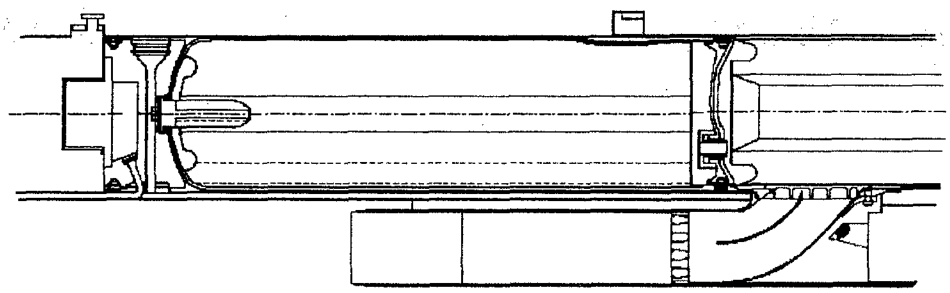

Figure 21 –Generic Unchoked Ducted Rocket Design

US/GERMAN DUCTED ROCKET

A joint international program was conducted between the U.S. and Germany with the objective of demonstrating next-generation ducted rocket ramjet technology. The program was started in 1989 and was concluded in 1999. ARC was the U.S. contractor and Bayern-Chemie was the German counterpart, each under contract to their respective Government office. Component development work was distributed equally to each contractor, with engine integration responsibility being shared. The program was concluded with a direct-connect engine test series at ARC (Figure 22).

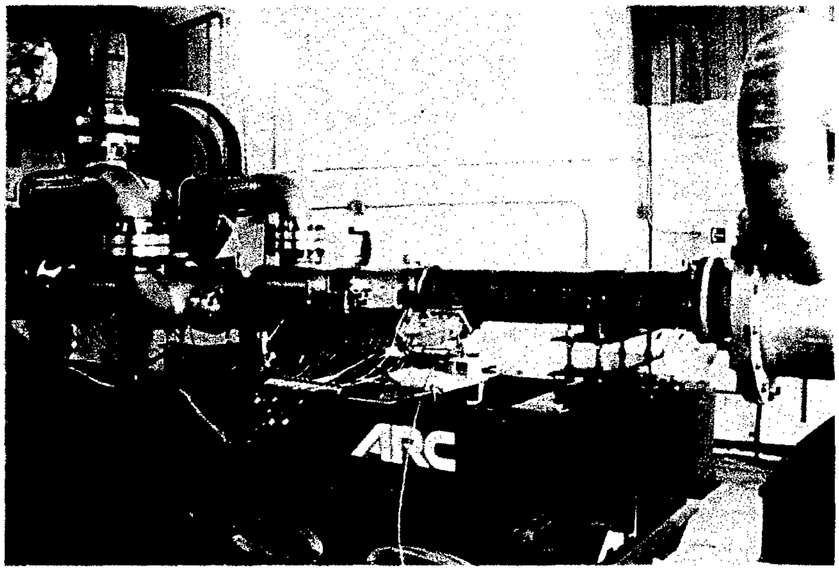

Figure 22 – US/German Ducted Rocket Testing

SOLID FUEL RAMJET MISSILE TECHNOLOGY PROGRAM

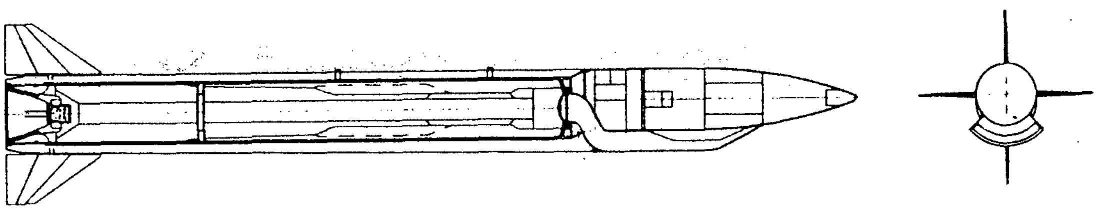

Figure 23 – Generic Solid Fuel Ramjet Engine Layout

Lockheed Martin Missiles and Fire Control - Dallas is the prime contractor for the Solid Fuel Ramjet Missile Technology Program sponsored by the Naval Air Warfare Center, Weapons Division, China Lake, California to develop affordable hypersonic missiles for future military applications. The program is developing a ramjet propulsion system using an airbreathing solid fuel ramjet (SFRJ) combined with carbon-carbon structural components. ARC is responsible for the ramjet engine design and ground testing. The SFRJ engine (Figure 23) carries fuel with no oxidizer, thereby offering efficient fuel packaging, and is consistent with the Military services' Insensitive Munitions requirements.

Development and testing performed under Phase I of the contract for the first time demonstrated continuous, stable thrust-producing SFRJ combustion at flight conditions representing cruise of Mach 5.7 at altitudes above 70,000 feet. The Phase II contract will demonstrate full-scale components and operation of the SFRJ at Mach 5.5 cruise conditions in 2003.

SUPERSONIC SEA SKIMMING TARGET (SSST)

The SSST missile target shown in Figure 24 (designated GQM-163A) is being developed by the Naval Air Systems Command, Program Executive Office for Strike Weapons and Unmanned Aviation, located at Patuxent River, Maryland. The SSST System is under development to provide the Navy with an affordable capability to meet early 21st century fleet training and weapons systems test requirements to simulate Anti-Ship Cruise Missiles. Orbital Sciences Corporation is the missile prime contractor, and is supported by Raytheon for missile avionics, and ARC for propulsion. The ARC contract covers a three-year development and flight-test program, and includes options for two years of production. The ARC SSST engine shown in Figure 25, designated the MARC-R-282, is based on the Variable Flow Ducted Rocket (VFDR) ramjet engine cycle. ARC has completed heavyweight ramjet engine development testing (Figure 26) to define the ramcombustor geometry, the solid fuel formulation, the fuel valve and injector design, and to verify assumed levels of engine performance. ARC recently expanded the ramjet test facility in Gainesville, Virginia to accomplish this development testing. The MARC-R-282 engine is now progressing into flight hardware, with flight testing planned to begin in early 2003.

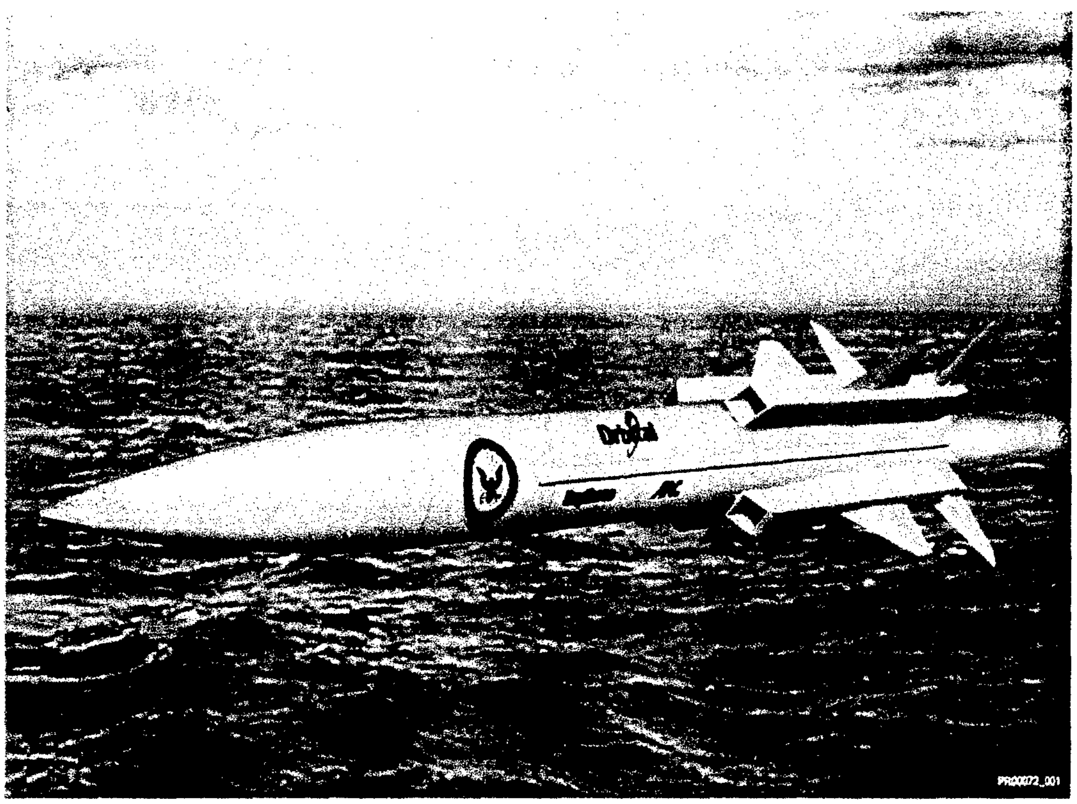

Figure 24 – SSST Missile Target (GQM-163A)

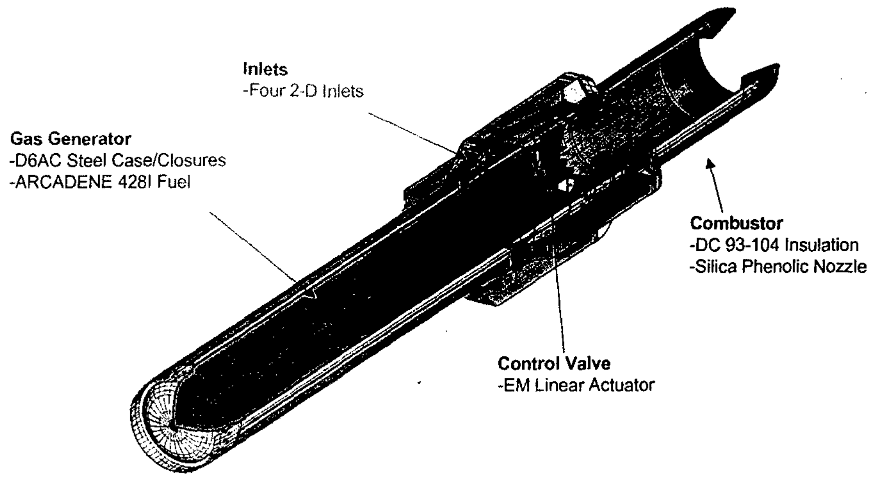

Figure 25 – MARC-R-282Ramjet

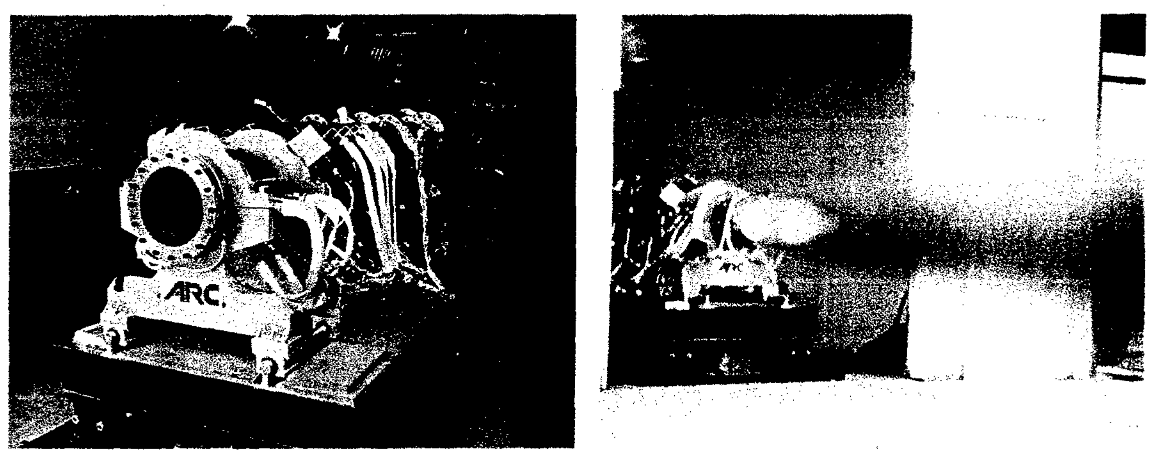

Figure 26 – MARC-R-282Ramjet Testing

HIGH SPEED ANTI-RADIATION MISSILE DEMONSRATION (HSAD)

The High Speed Anti-Radiation Demonstration (HSAD) Project is focused on maturing an advanced propulsion concept that is compatible with the guidance, navigation and control (GNC) section of the Air-Ground Missile-88E (AGM-88E), Advanced Anti-Radiation Guided Missile (AARGM) Program. The HSAD Project obtained mission/operational/system level guidance from the Operational Navy Requirement Officer (N780C6) and the Defense Suppression Program Office (PMA 242). From this guidance, a trade study of various concepts was conducted based on performance, cost and schedule. The concept that was rated the highest based these factors is an Integral Rocket Ramjet (IRR) incorporating a nozzleless booster rocket and variable flow rocket (VFDR) ramjet. A unit incorporating this propulsion system will be designed, developed, fabricated, tested, undergo controlled test vehicle (CTV) integration, captive carried, air launched and free flight tested.

ARC has been selected by the U. S. Naval Air Warfare Center-Weapons Division to develop the ramjet propulsion system for HSAD. The solid-fueled ramjet engine, which is based on demonstrated ARC technology, will increase the performance of future anti-radiation missile systems. ARC's ramjet-powered design shown in figure 27 increases the range and decreases the time-to-target, compared with existing missile capabilities, directly enabling the Navy's transformation to next-generation weapons systems.

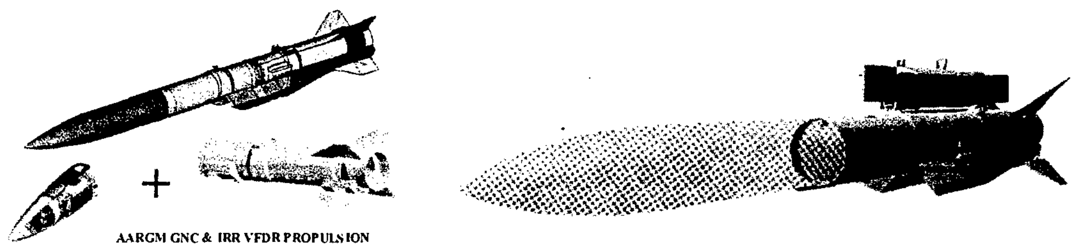

Figure 27: HSAD Configuration

The 42-month program will include ground testing that leads to delivery of three flight test systems to provide a test bed for an upgraded seeker. A successful demonstration program may lead to future development and production programs.

SUMMARY AND FUTURE OUTLOOK

Greater standoff ranges and reduced time to target are consistently mentioned in conjunction with future US missile requirements. Ramjet or scramjet solutions certainly provide the kinematic properties desired, but remaining factors such as affordability, payload integration, inlet packaging, and development risk all play important roles in a selection process. The attractive performance attributes of ramjet-powered missiles have been available for over 50 years, yet limited applications have come to being. Recent advances in integral booster design may help reduce many system level concerns, and advances in targeting and information technology may create the need for the added range that ramjet propulsion can supply.

A very strong international ramjet capability is being created through several significant ongoing missile developments. While propulsion approaches to future US weapon requirements continue to evolve, thankfully it appears that the combination of current US ramjet programs have served to revive and reinvigorate a new generation of industrial and military ramjet capability.